The Influence of Directional Sampling on Bidirectional Reflectance and Albedo Retrieval Using Kernel-Driven Models

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Abstract – The error in bidirectional reflectance and albedo retrievals due to random noise in the observed reflectances is found to be less than the noise RMSE using 16-day MODIS-MISR angular sampling.

INTRODUCTION

Global space-based retrievals of the bidirectional reflectance distribution function (BRDF) and albedo over land will be possible in the near future using the Earth Observing System's (EOS) MODIS and MISR sensors or the POLDER instrument. BRDF information is useful for normalizing satellite-acquired data sets and for deriving key surface parameters, mainly atmospherically corrected albedo for use in climate studies.

Little work, however, has been done on the sensitivity of BRDF and albedo retrievals to angular sampling patterns even though the impact of these on product accuracy is possibly substantial. With any instrument, the angular distribution of samples obtainable in a given time period will vary with geographic latitude and time of year, and be also determined by instrument and orbit characteristics. Cloud masking will further reduce the set of available angular reflectances. In this paper we evaluate in a practical case the impact of angular sampling effects on BRDF and albedo derivation.

Two effects mainly have an influence on retrieval accuracy as a function of angular sampling:
(1) Sensitivity to random noise. Analysis is carried out under the assumption that the RMSE found in inverting a model against observations is due to random "noise-like" errors in the observed reflectances, due for example to fluctuations in surface properties, misregistration, atmospheric correction errors etc.
(2) Misfit sensitivity. Analysis is carried out under the assumption that the RMSE found in inversion is due to an inherent partial inability of the model used to fit the observations even in the absence of "noise". Investigating this effect is important in view of the many assumptions that are commonly made in operationally feasible BRDF models.

In this paper, we focus on the noise sensitivity analysis alone, although the misfit analysis is of equal importance (selected results are presented in the paper Wanner et al. [1] at this conference). We study the behavior of semiempirical BRDF models under conditions of sampling by MODIS and MISR, and how the semiempirical Rahman model [2] behaves under the same circumstances.

THE EXPERIMENT

We here investigate sampling effects with respect to the MODIS BRDF/albedo product, using the sampling patterns and BRDF models characterizing it. The product is slated for production at a spatial resolution of one kilometer once every 16 days and in seven spectral bands from combined MODIS-AM and MISR data starting in 1998. The MODIS-AM sensor is an across-track imager with a swath width of 2330km, and a repeat rate shorter than 2 days (mostly shorter than 1 day). MISR is an along-track imager with a swath width of 364km using four fore-, four aft- and one nadir-pointing camera. The two-look repeat rate is 16 days. In this time, each sensor produces a string of observations across the viewing hemisphere with rather constant relative azimuth and solar zenith angles. The two strings from the two instruments are nearly orthogonal; their respective azimuthal distance from the principal plane varies with latitude and time of year, as does the mean solar zenith of the observations and the number of observations from MODIS.

The analysis was carried out for the BRDF models that are scheduled for use in the MODIS BRDF/albedo product: the RossThick-LiSparse, RossThin-LiSparse, RossThin-LiDense, RossThick and LiDense semiempirical kernel-driven BRDF models [3]. These are capable of modelling a wide variety of volume and surface scattering behavior and which will be employed depending on the scattering behavior observed.

NOISE SENSITIVITY OF KERNEL-DRIVEN MODELS

The behavior of kernel-driven linear models under the conditions of limited and varying angular sampling can be studied analytically due to the mathematical form of these models. It is given by the the so-called "weights of determination", calculated using theory that originates with Gauss [4]. Kernel-driven models give the reflectance R in form of a sum, $R = \sum f_i k_i$, where f_i are the model parameters and k_i are mathematical functions ("kernels") giving basic BRDF shapes depending only on sampling geometry. The expected error in a term u given by a linear combination of model parameters, $u = \sum f_i U_i$ (e.g., R itself at a given combination of angles, or integrals of the BRDF such as directional and diffuse albedo), is given by $\epsilon_u = e/\sqrt{w_u}$, where e is the estimate of standard error in the observed data (approximated by the RMSE in model fitting), and $1/w_u$ is the weight of determination of term u under the sampling considered. This weight is given through

$1/w_u = [U]^T[M^{-1}][U]$, where U is a vector composed of the terms U_i and M^{-1} is the inverse matrix providing the analytical solution to the problem of inverting a set of reflectances R_i for model parameters f_i minimizing a given error function. Note that this analysis is independent of any specific BRDF function.

In an extensive investigation, we have studied the sensitivity to random noise of the several BRDF models listed above using sampling for a variety of combinations of the MODIS and MISR sensors, and for different periods of data accumulation. From these, we here report selected findings on 16-day sampling only for 3 different sensor combinations. Both interpolating and extrapolating the BRDF were tested in that nadir reflectance and directional-hemispherical ("black-sky") albedo were derived both at the mean sun angle of the observation and for nadir sun. Additionally, bihemispherical ("white-sky") albedo and the model parameters themselves were investigated.

Table 1 summarizes findings. The base case studied was 16-day sampling for combined MODIS and MISR data, as for the MODIS BRDF/albedo product. We further investigate whether using MODIS data alone is an option, and whether a second MODIS sensor to be launched on the EOS-PM-1 platform is a potential substitute for MISR in view of the three additional bands that MODIS has over MISR. Table 1 lists first the median weights of determination found for sampling throughout the year and at all latitudes. Given are the values found for the BRDF model with the smallest and with the largest median weight. Second, it gives the worst-case range of values. Range here is defined as the central two thirds of values occurring.

Results show that the MODIS-AM/MISR sensor combination will allow retrieval of the BRDF with an accuracy that is smaller than the RMSE of the inversions (weights if determination smaller than one). Retrieval of nadir reflectance and black-sky albedo at the mean prevailing sun zenith angle is very stable and more reliable than deriving these quantities for a nadir sun. But even the latter, requiring extrapolation of the BRDF to angles where typically no observations were made, is possible with an accuracy of less than the value of the RMSE. The same is true for the white-sky albedo. The expected error of the model parameters themselves is larger than that of derived quantities. Naturally, cloud cover will increase these error estimates. Assuming that the angular distribution of samples is not affected by loss of observations due to clouds, the weights of determination can be shown to increase as $1/\sqrt{N}$, where N is the number of observations.

Using the MODIS-AM sensor alone yields a worse product quality, notably for nadir-view nadir-sun totally angle corrected reflectance, and nadir-sun albedos. This emphasizes the importance of combining MISR data with MODIS data for a sound retrieval. The MODIS-AM/MODIS-PM sensor combination will allow a better retrieval than when using MODIS-AM alone, but is not as good as using MODIS-AM/MISR. This suggests that MISR should also be used in retrievals after the launch of MODIS-PM in the four bands concerned.

Fig. 1, in the top two panels, visualizes the dependence of noise-induced error in BRDF-interpolating and BRDF-extrapolating reflectances and albedos on latitude and time of the year for MODIS-AM/MISR sampling and for the RossThick-LiSparse model. An RMSE of 10 percent was assumed in

converting weights of determination to percentage error (note that errors scale linearly with the RMSE). The plots illustrate nicely that interpolation of the BRDF can be conducted with confidence, but that the error of extrapolation also is less than the assumed noise RMSE.

NOISE SENSITIVITY OF THE RAHMAN MODEL

The RPV BRDF model [2] is slated for use in the MISR BRDF/albedo product. It is here investigated for MODIS-AM/MISR 16-day sampling for comparison. Since it is a nonlinear model, noise sensitivity is a function of spectral band and BRDF observed, and studying it required tedious numerical evaluation. Using four field-observed BRDF types and five levels of noise in 250 individual random realizations, equivalent weights of determination were derived. The finding is that with respect to reflectances and albedo the RPV model behaves rather similar to the kernel-driven models; the retrievals are of comparable reliability. However, at least two of the model parameters themselves are instable (weights of determination $\gg 10$) due to redundancy of the respective BRDF component functions in the angle domains sampled.

Fig. 1 shows, in the bottom panels, results for the red and the near-infrared band for one day of the year using a field-measured hardwood BRDF dataset by Kimes et al. [5]. Note similarities and differences with the RossThick-LiSparse model shown in the top left panel for the same day.

CONCLUSIONS

BRDF and albedo c. n be retrieved from noisy reflectance data both at the prevailing mean sun angle of observations and at other angles to within a fraction of the noise RMSE under conditions of angular sampling as obtained from the combined MODIS and MISR sensors, and using kernel-driven BRDF models or the RPV model.

In judging the results it is important that the random noise error investigated here implies little about a second type of error, the misfit error, which is essential in determining how well a given model extrapolates. Only after judging noise sensitivity and misfit error together, and considering actual sampling patterns, can general conclusions about BRDF/albedo retrieval accuracies be drawn.

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Table 1: Median Weights of Determination (left) and Worst-Case Ranges of Weights of Determination (right).
Left: smallest and largest median error of models; Right: smallest and largest worst case model error.

16–day sampling		Median Error Weights			Worst-Case Ranges of Error Weights		
		MODIS–AM + MISR	MODIS–AM	MODIS–AM+PM	MODIS–AM	MODIS–AM	MODIS–AM+PM
Interpolation	Rnad	0.18–0.23	0.30–0.40	0.17–0.23	0.18–0.28	0.29–0.44	0.17–0.25
$\theta_s = \langle \theta_s \rangle$	bsa	0.16–0.18	0.25–0.55	0.15–0.29	0.15–0.20	0.40–0.72	0.23–0.41
Extrapolation	Rnad	0.17–0.93	0.28–3.45	0.16–1.94	0.73–1.08	1.47–5.72	0.86–3.18
$\theta_s = 0$	bsa	0.18–0.28	0.29–0.82	0.17–0.45	0.19–0.49	0.30–2.54	0.17–1.47
Global, $\int \theta_s d\theta_s$	wsa	0.17–0.42	0.31–1.60	0.18–0.95	0.21–0.82	0.66–2.42	0.40–1.41
Parameters	f_{vol}	0.15–0.89	0.39–2.01	0.23–1.19	0.33–1.76	1.21–3.52	0.72–1.97
	f_{geo}	0.27–0.60	0.68–2.32	0.39–1.28	0.45–0.69	0.99–3.73	0.58–1.99

Rnad = reflectance at nadir view angle; bsa = black-sky albedo; wsa = white-sky albedo; f_{vol} = volume scattering kernel coefficient; f_{geo} = surface scattering kernel coefficient.
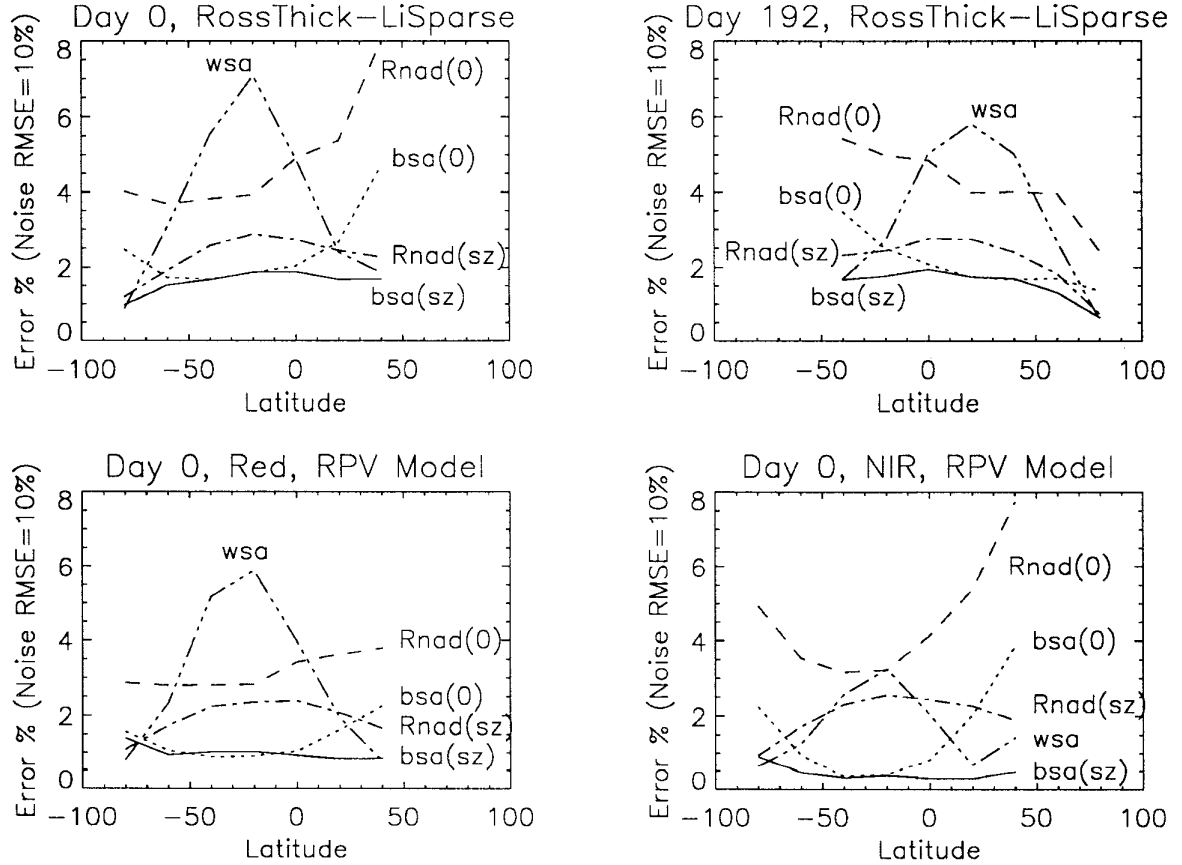

Figure 1: Noise error sensitivity of the RossThick-LiSparse semiempirical BRDF model for 16-day MODIS/MISR sampling on two different days of the year (top) and for the Rahman model (bottom) for the red (left) and NIR (right) band on Kimes hardwood data; Rnad(sz), bsa(sz) = nadir-view reflectance and black-sky albedo at mean sun zenith; Rnad(0), bsa(0) = nadir-view reflectance and black-sky albedo at nadir sun; wsa = white-sky albedo.